GRAPEVINE LAKE MODELING & WATERSHED CHARACTERISTICS

Photo Credit: Lake Grapevine – Boat Ramps

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GIS in Water Resources

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Introduction

Figure 1: Grapevine Lake Location (TWDB)

After World War 2, the U.S. Congress enacted the River & Harbors Act of 1945 on March 2nd which provided for the construction of several lakes including Grapevine Lake. As part of this act the Grapevine Dam and Reservoir project began in January 1948 when the Army Corps of Engineers dammed Denton Creek in the Trinity River's Elm Fork. Completed in June 1952 and impounded with water that July, Grapevine Lake provides flood control to the Dallas-Fort Worth Metroplex area, and acts as water storage and supply for Dallas, Fort Worth and Grapevine in addition to serving as recreational waters for camping, fishing, and boating (US Army Corps of Engineers).

Objectives

The objectives of this term project are to characterize the drainage basin that contributes to Grapevine Lake, to compare historic water levels with drought data, and to develop a bathymetric model of the lake. Characterization of the lake basin include an analysis of the subwatersheds, catchments, stream topography, land cover and a hydrologic terrain analysis using a digital elevation model.

Methods and Results

Data Sources

NFIE: Vector polygon data from the National Flood Interoperability Experiment by CUAHSI was utilized to delineate the subwatersheds and catchments contained within the Grapevine Lake drainage basin.

NHD: Vector polyline data from the National Hydrography Dataset was incorporated to acquire the stream reaches contained within the Grapevine Lake drainage basin.

NLCD: Raster data from the National Land Cover Dataset was imported to classify the land cover and the area corresponding to each land class within the drainage basin.

NED: Raster data from the National Elevation Dataset was incorporated to depict a digital elevation model for the drainage basin, as well as to complete a hydrologic terrain analysis.

TWDB: Vector polyline data was collected from a 2011 survey of Grapevine Lake by the Texas Water Development Board, and the affiliated Water Data for Texas provided reservoir storage history.

U.S. Drought Monitor: Vector polygon data was acquired from the U.S. Drought Monitor for comparison to the historic reservoir storage of Grapevine Lake.

Results and Discussion

The first step in this project was to delineate the drainage basin contributing to Lake Grapevine. Using the World Geodetic System 1984 geographic coordinates for the lake (32° 58′ 20″ N, 97° 3′ 24″ W), the Watershed function from the Ready-to-Use Hydrology tool was applied to bound the drainage basin which spans 1799 km^2. Additionally, using the Trace Downstream function in the same toolbox it was determined that ultimately discharge from the lake enters the Trinity Bay near Galveston.

Subwatersheds

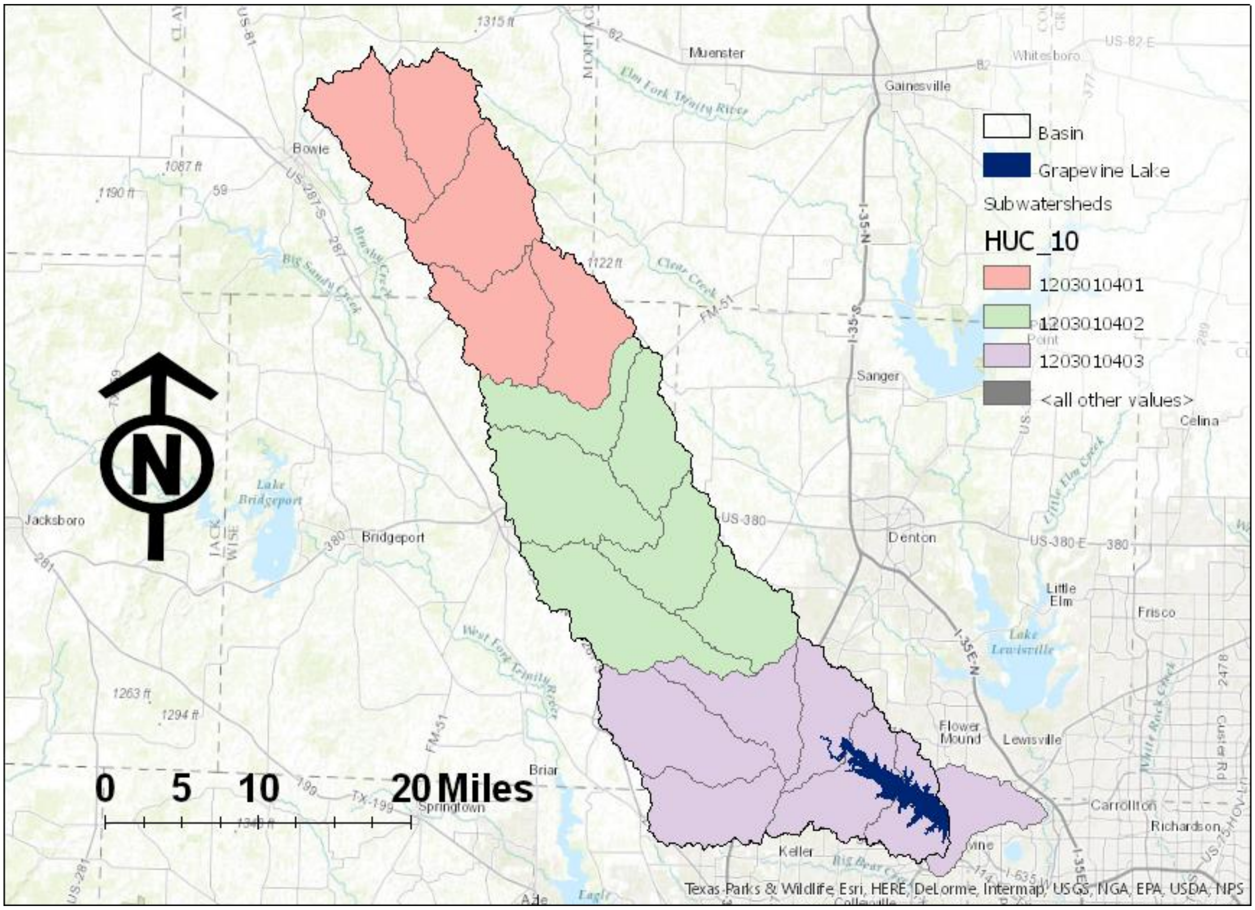

Figure 2: Subwatersheds Comprising the Grapevine Lake Drainage Basin

Once the drainage basin had been delineated, data from the NFIE Geodatabase was applied to the map. Subwatersheds matching the Hydrologic Unit Code (HUC) 8 for the Denton Watershed subbasin (12030104) were then overlaid onto the drainage basin. The Denton Watershed subbasin contains 18 subwatersheds including all 17 of the subwatersheds within the drainage basin and one additional subwatershed corresponding to the discharge zone of the lake. These 18 subwatersheds are classified into the 3 HUC 10 watersheds shown in Figure 2.

Catchments

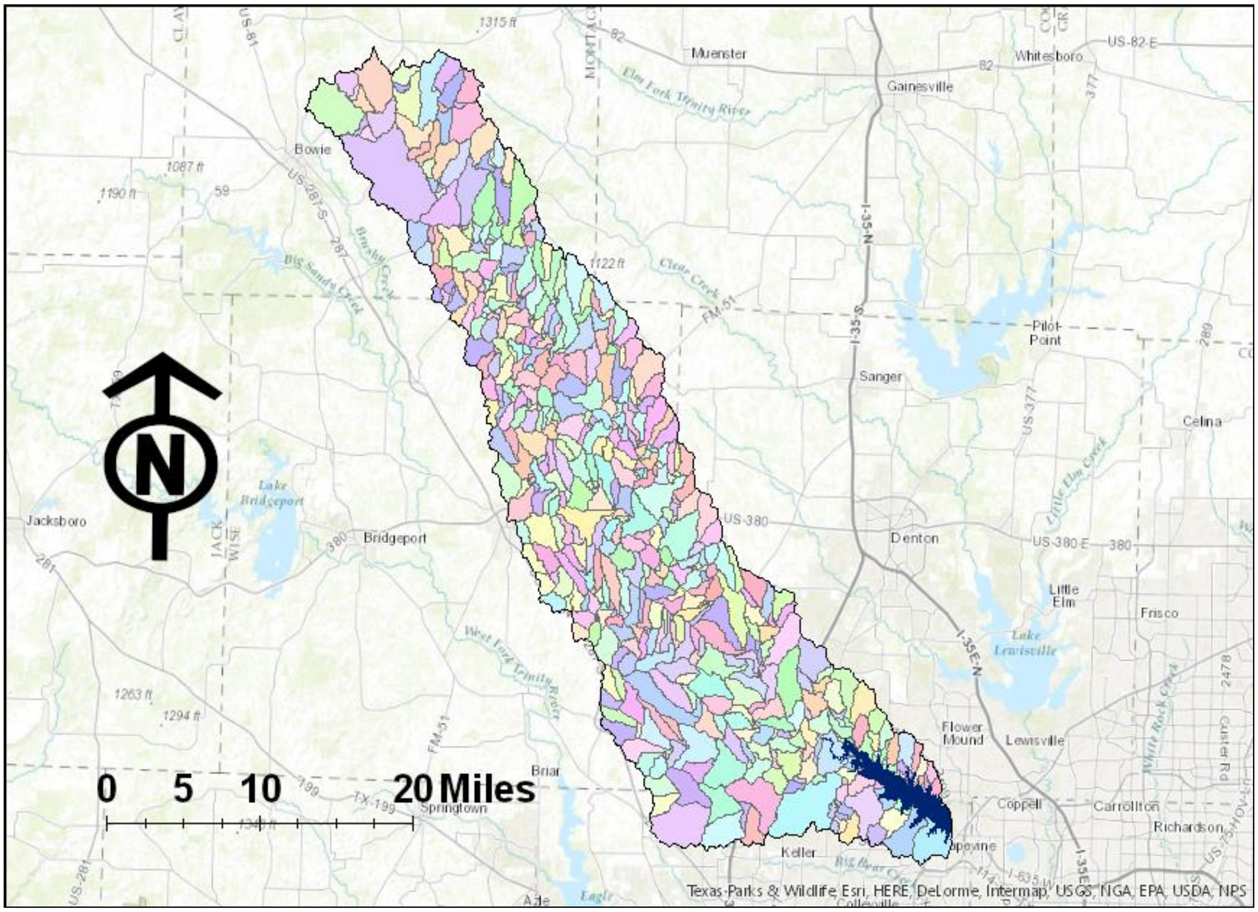

Figure 3: Catchments Within the Grapevine Lake Drainage Basin

The catchment data from the NFIE Geodatabase was then overlaid with the drainage basin and catchments which have a center located in the drainage basin were extracted. In the Grapevine Lake drainage basin, there are a total of 596 unique catchments shown in Figure 3.

Streams

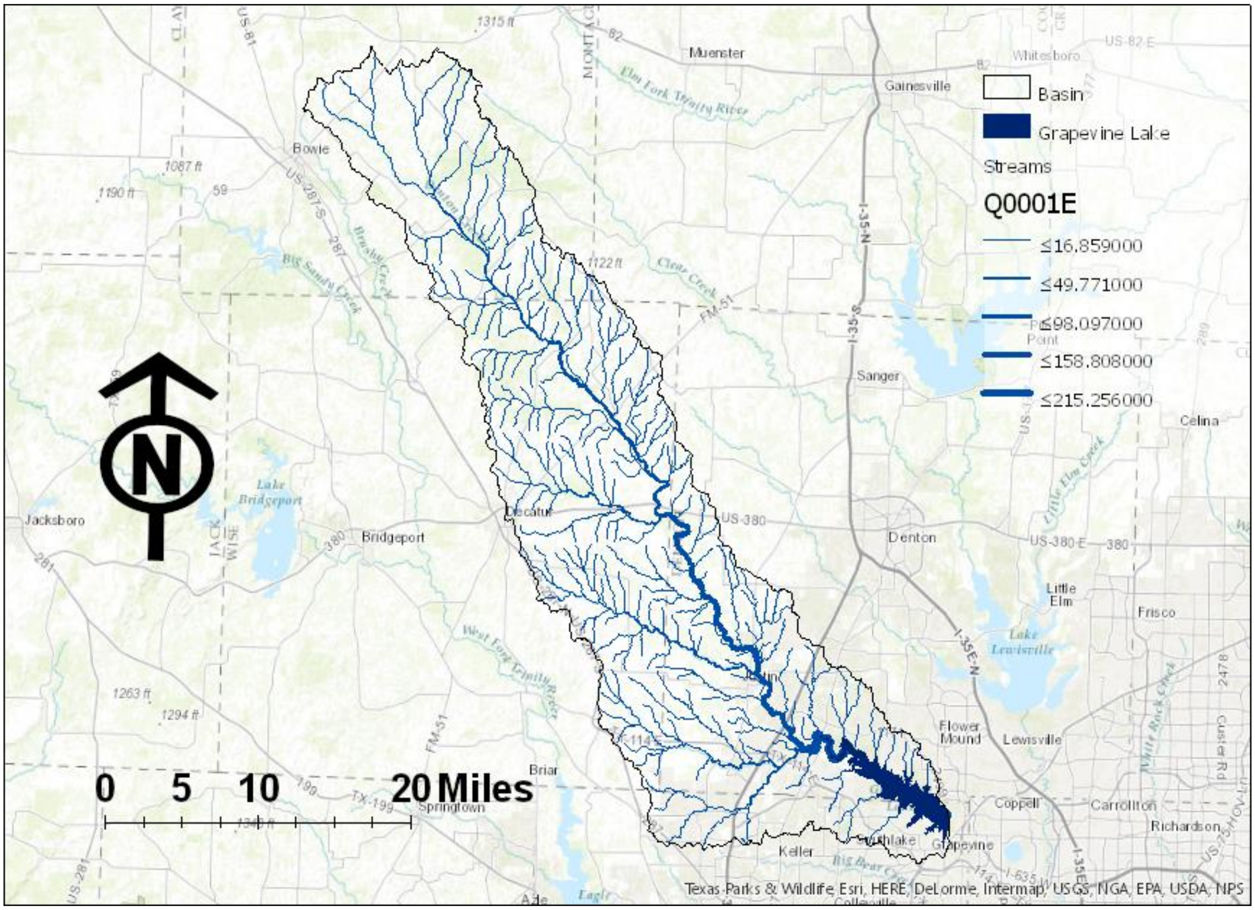

Figure 4: Streams in the Grapevine Lake Drainage Basin

Next, to establish the stream topography within Grapevine Lake's drainage basin the NHDPlus V2.1 vector data from the Landscape1 ArcGIS server was imported into the project. Using the Extract Landscape Source Data function of the Extract Data tool in this server with the Seamless Flowlines over the basin, the stream data was extracted from the server within the bounds of the drainage basin. In the Grapevine Lake drainage basin, there are a total of 604 streams totaling about 1326 km. The number of streams within the drainage basin is slightly higher than the number of catchments determined previously, likely due to the National Hydrography Dataset providing a more complete stream characterization.

Land Cover

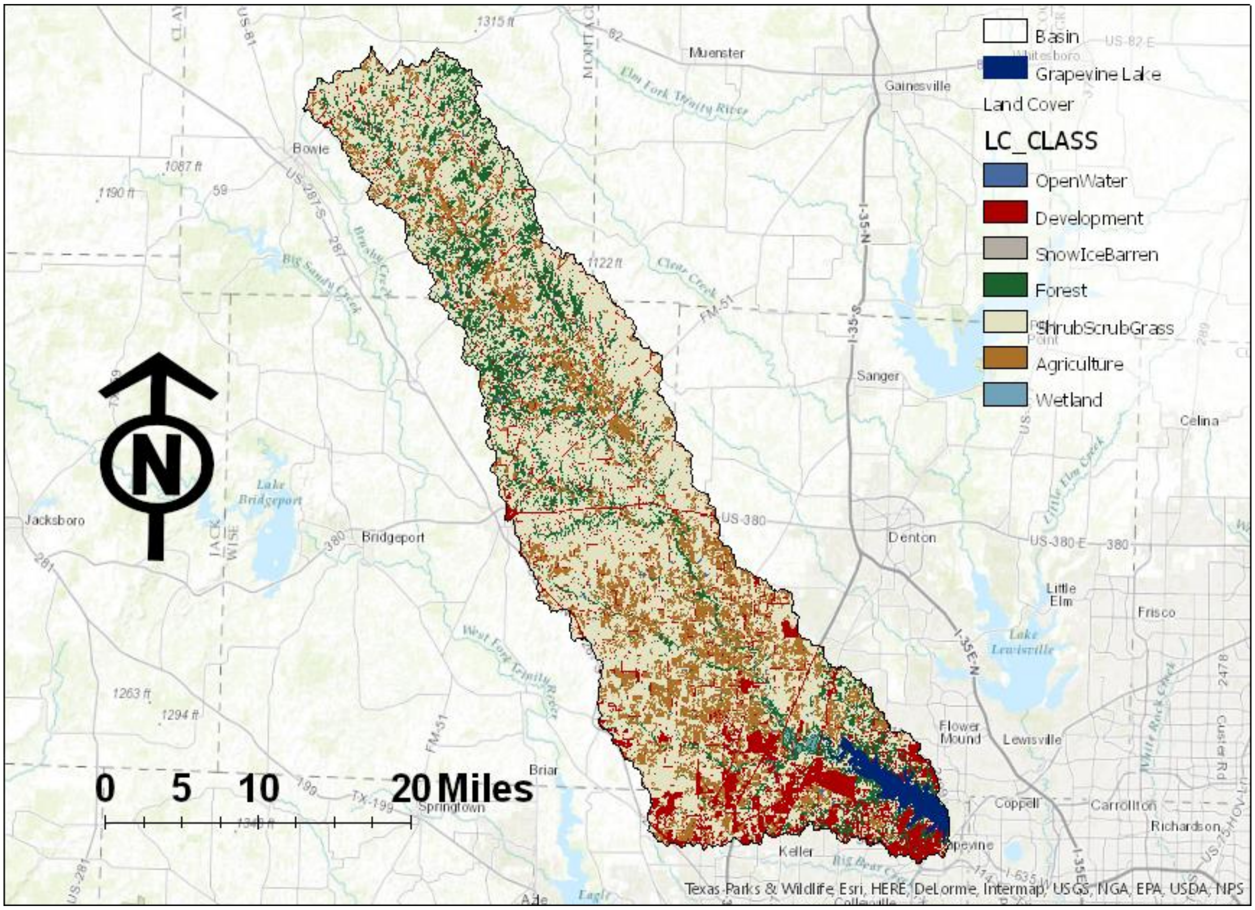

Figure 5: Land Cover for the Grapevine Lake Drainage Basin

After capturing the streams within the drainage basin, the next step was to interpret the land cover. The 2006 National Land Cover Database raster data from the Landscape 2 ArcGIS server was imported into the project and then using the Extract by Mask function in the Spatial Analyst Extraction Tool. Land cover as a percentage of the drainage basin and in terms of area is presented in Table 1.

Table 1: Land Cover Area Composition

Land Cover	Area (%)	Area (km^2)
Agriculture	18.00%	323.88
Development	11.55%	207.88
Forest	13.80%	248.32
Open Water	2.05%	36.87
ShrubScrubGrass	54.12%	973.64
SnowIceBarren	0.15%	2.64
Wetland	0.33%	5.86

Digital Elevation Model

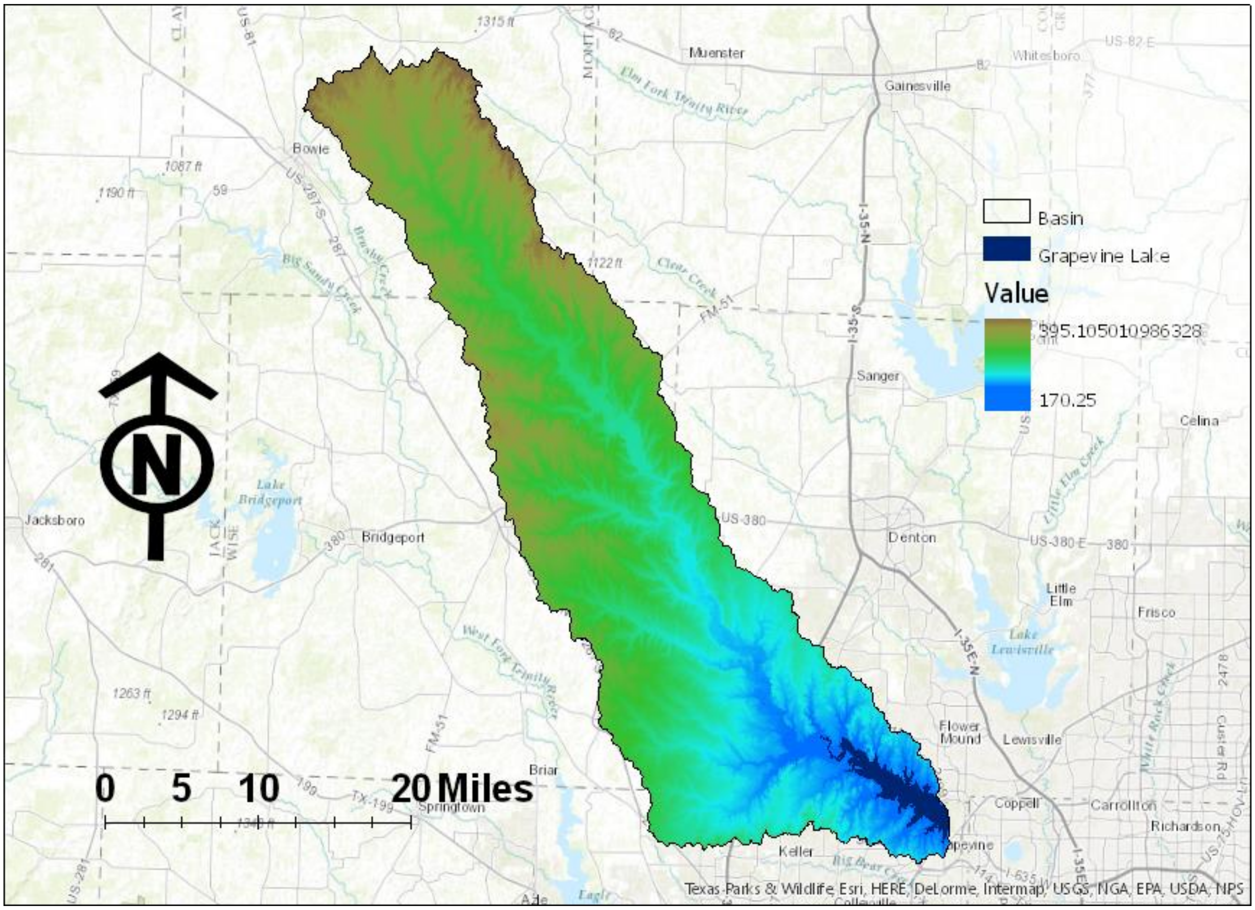

Figure 6: Digital Elevation Model of the Grapevine Lake Drainage Basin

To begin characterizing of the land surface within the drainage basin, the National Elevation Dataset 30m (NED30) data was imported into the project from the Elevation ArcGIS server. The resulting digital elevation model was extracted to the bounds of the drainage basin as seen in Figure 6, as well as to a 1 km buffered basin for further analysis. Within the drainage basin the elevation ranges from about 170 meters near Grapevine Lake to about 395 meters along the northern edge of the basin.

Flow Direction

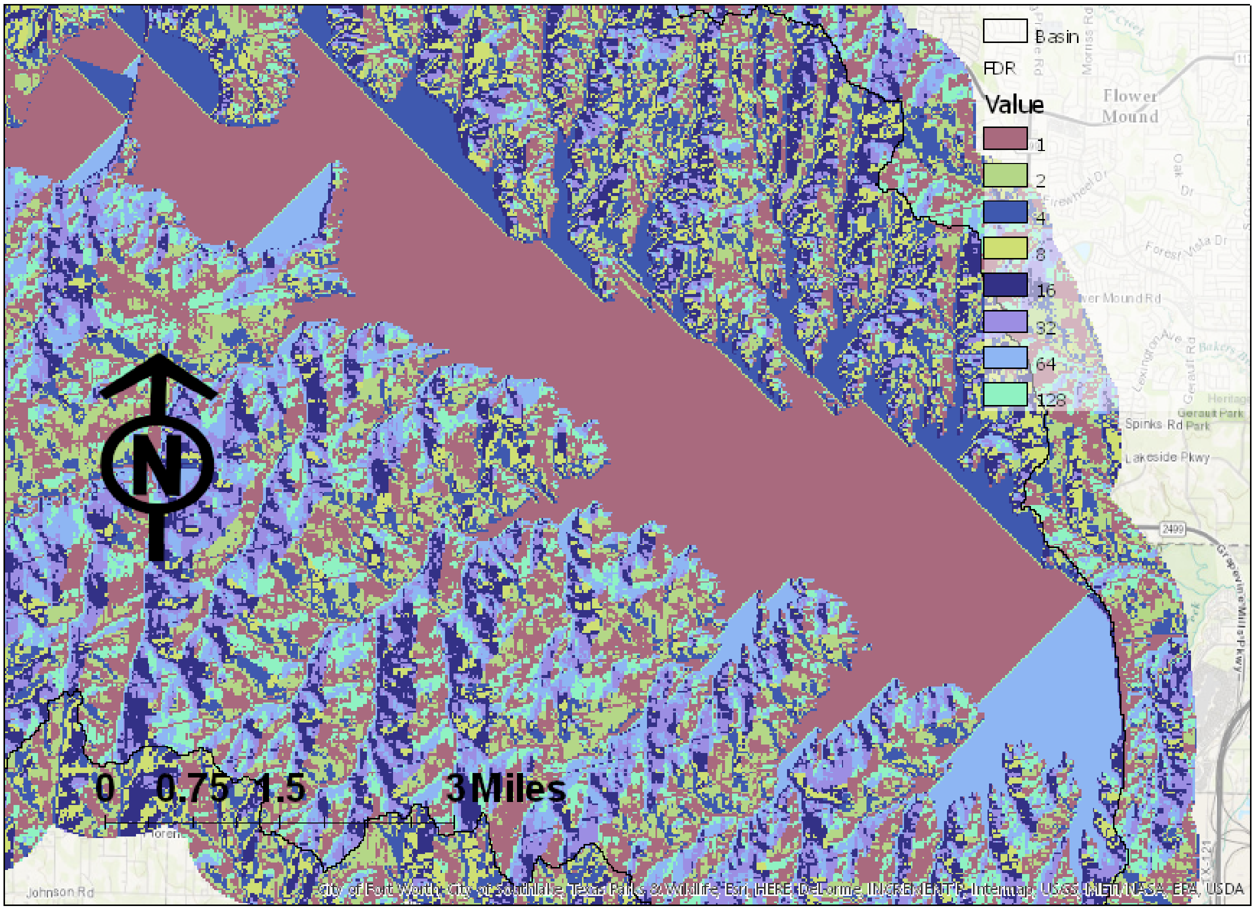

Figure 7: Flow Direction Around Grapevine Lake

Prior to further analysis the DEM raster contained within the buffered basin was conditioned using the Fill function in the Spatial Analyst Hydrology tool to eliminate any sinks. Next, using the Flow Direction function from the same Hydrology tool the direction of steepest descent for the raster grid cells was established. The results of this analysis near Grapevine Lake are shown above in Figure 7, which indicates that the digital elevation model considers the lake surface to be the land elevation and thus all the flow is diverted to the eastern edge of the lake.

Land Slope

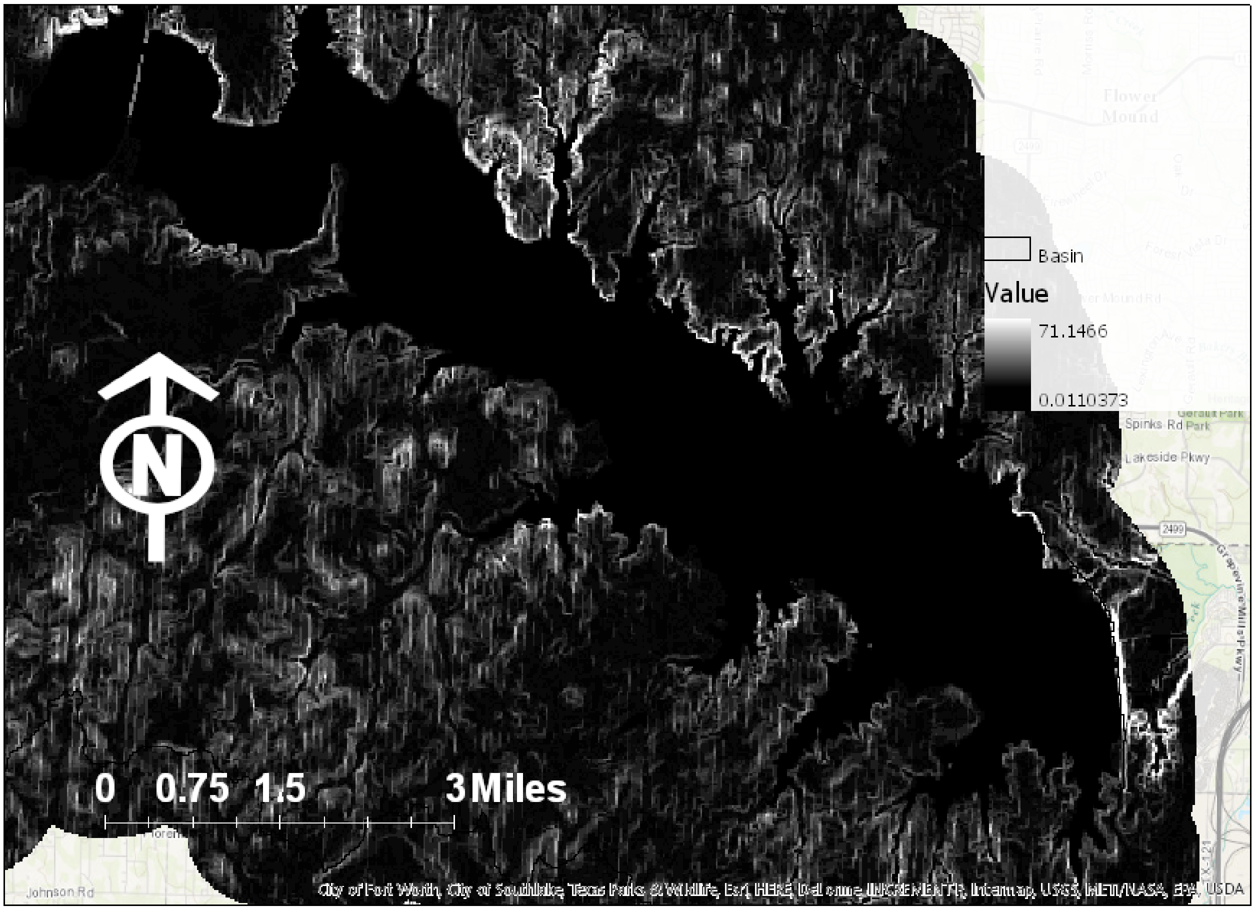

Figure 8: Land Slopes Around Grapevine Lake

Using the Flow Direction function from before the other output obtained was a raster of the land slope as a percentage drop in elevation. Within the basin, the slope varies from approximately zero to 71%, as indicated in Figure 8. Similar to the acquired flow direction raster, the land slope raster indicates a flat land surface along the lake's surface.

Flow Accumulation

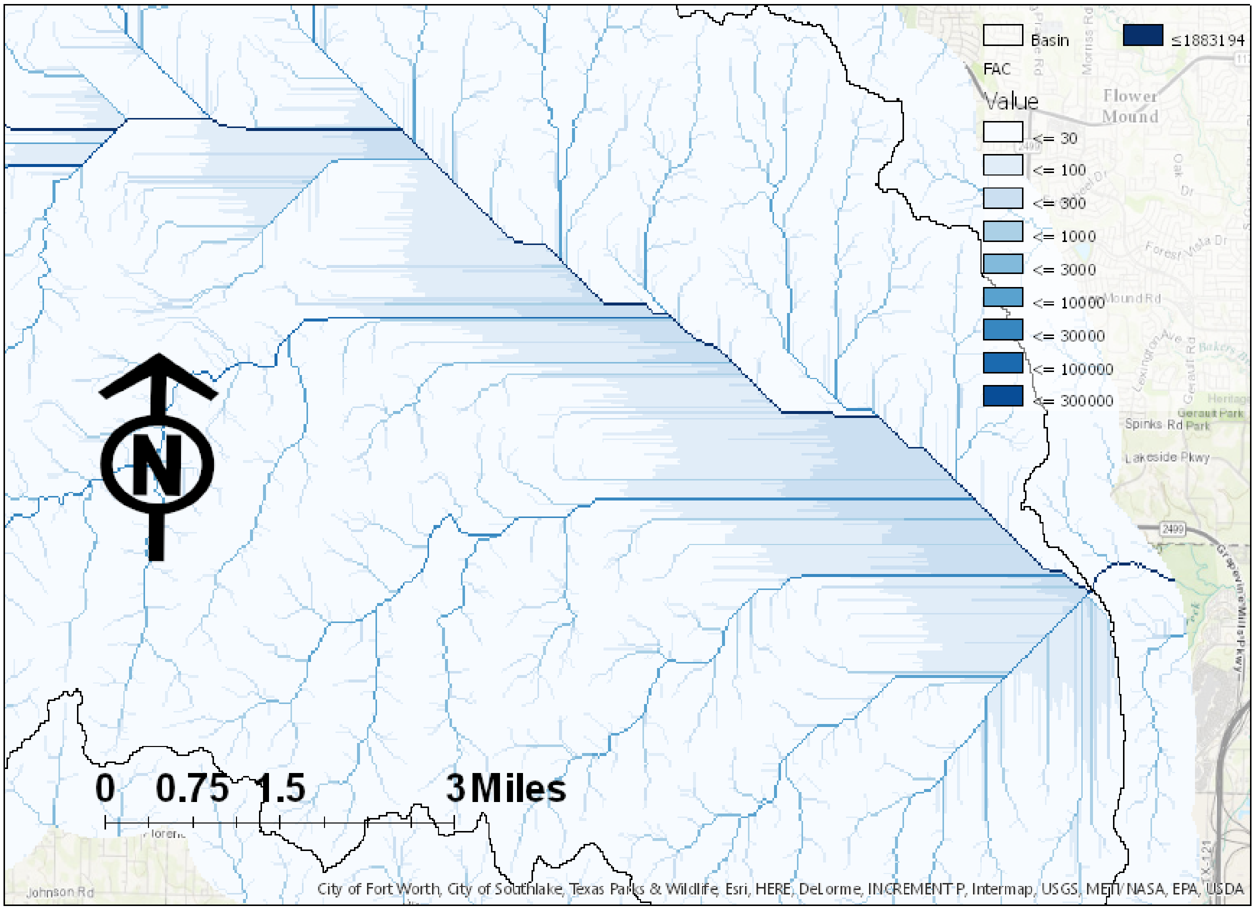

Figure 9: Flow Accumulation Around Grapevine Lake

The final step of the hydrologic terrain analysis was to determine the flow accumulation in each of the raster cells within the basin. This was achieved using the Flow Accumulation function in the Spatial Analyst Hydrology tool with the flow direction raster as an input. While the accumulation in the basin in areas further from the lake is representative of the streams acquired from NHDPlus, results from this analysis shown in Figure 9 indicate the same trend as the other hydrologic terrain analyses. Specifically, that the flow tends to accumulate over the surface of the lake as though it were a flat surface and travel to the path of least resistance towards the discharge point which causes the straight lines shown.

Historic Drought Comparison

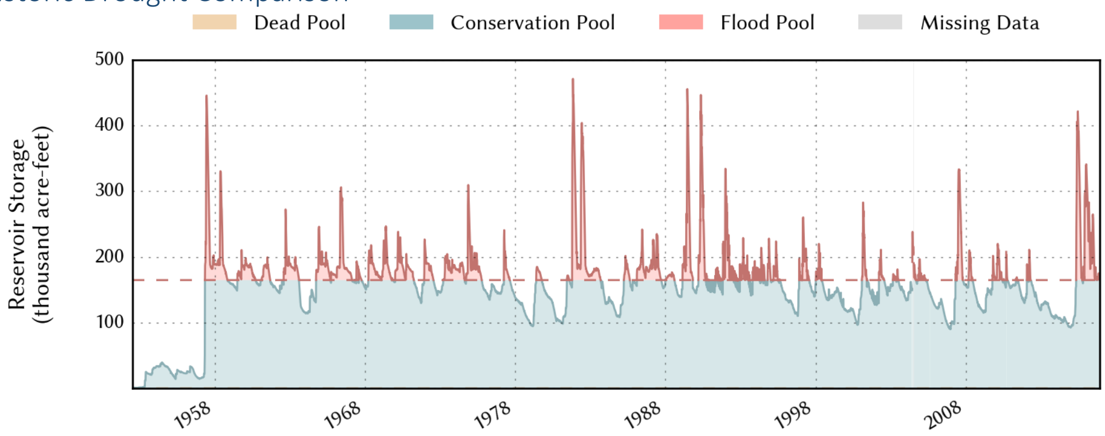

Figure 10: Reservoir Storage for Grapevine Lake Since 1952 (TWDB)

After characterizing the lake's drainage basin, the next objective was to compare historical reservoir storage to drought data to determine if the two are correlated. Figure 10 above indicates the reservoir storage for Lake Grapevine since 1952 when it was impounded with water. The dashed line in the figure represents the reservoir storage corresponding to conservation pool elevation. When the lake is above the dead pool elevation indicating zero fill, and up to the conservation pool elevation, Grapevine Lake is considered a conservation pool as shown in blue on the reservoir storage plot. Between the conservation pool elevation and the flood pool elevation the lake is considered a flood pool as shown in red. When the lake reaches elevations above 560 feet an emergency spillway is activated to avoid the lake reaching the maximum design elevation. In addition, there is a factor of safety of about 6 feet between the maximum design elevation and the top of the dam to prevent overflow. A summary of the key elevations for the lake is indicated in Table 2.

Table 2: Grapevine Lake Key Elevations

Classification	Elevation (ft)
Dead Pool	475
Conservation Pool	535
Flood Pool/ Emergency Spillway	560
Max Design Elevation	581.9
Top of Dam	588

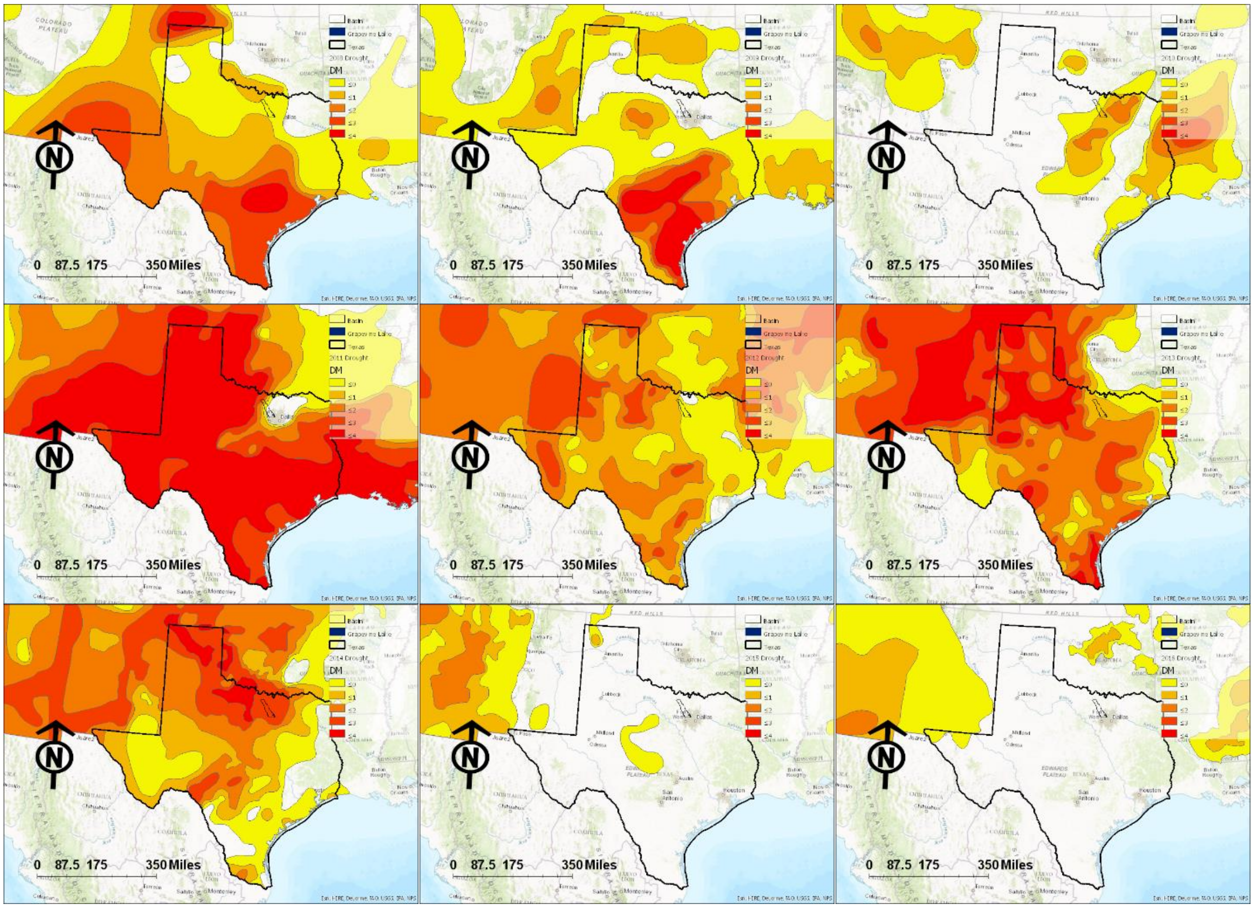

Figure 11: 2008-2016 Summer Droughts

To determine the relationship between the reservoir storage and historic drought, shapefiles of the weekly measured drought from the United States Drought monitor were overlaid on the base map. Since drought data is only available back to 2006, a range from 2008 to 2016 was selected for simplified comparison to the reservoir storage plot. Data was chosen for measurements as near to the arbitrary date of July 1 as could be obtained. On the maps above in Figure 11 the yellow area represents abnormally dry conditions, light orange represents moderate drought, orange signifies severe drought, red-orange indicates extreme drought, and red shows exceptional drought. Comparing these yearly figures to the reservoir storage data where there are lows corresponding nearly to 2010 and 2012-2014 it is apparent that drought is indicative of periods where the Lake has been considered a conservation pool.

Bathymetric Model

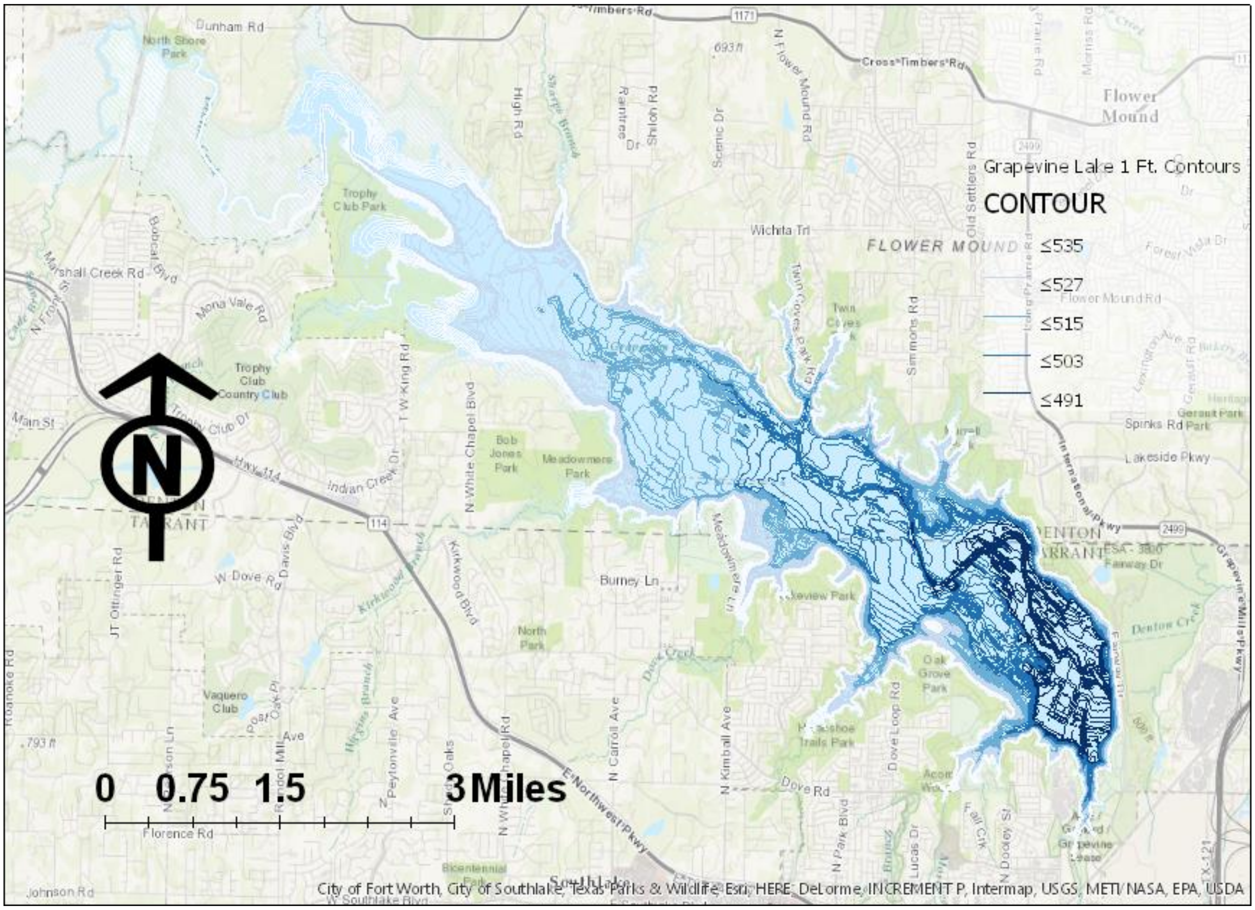

Figure 12: Grapevine Lake 1 Ft. Contours

After performing the hydrologic terrain analysis, it became clear that the digital elevation model does not accurately represent open water bodies. The final objective of this project was to develop a bathymetric model for the lake that considers the contours of the land below surface elevation to improve hydrologic terrain analysis and enable more accurate further analysis such as determining the height above nearest drainage. To begin modelling the lake bathymetrically contour shapefiles were acquired from a 2011 survey of Lake Grapevine by the Texas Water Development Board. The survey provides contours at 10, 5, 2 and 1 foot intervals, the latter of which is depicted in Figure 12 above.

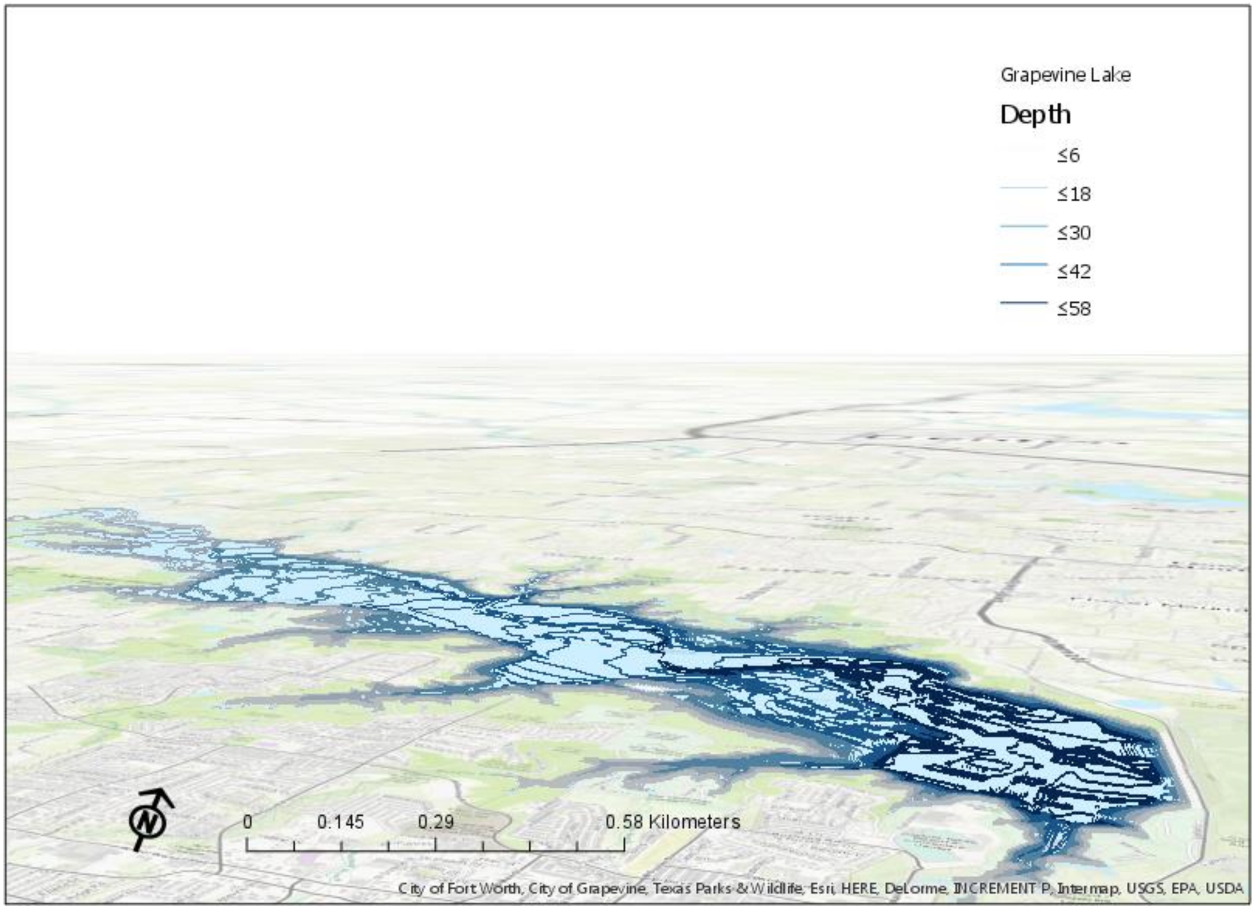

Figure 13: Grapevine Lake Bathymetric Model

Initially, 1 foot contour lines were chosen for modelling the bathymetry of the lake in 3D; however, it was quickly discovered that rendering the model at this scale was unachievable, thus contours in 2 ft. intervals were selected. After adding a depth field to the attribute table for the contour feature, the Calculate Field function in the Data Management Fields tool was applied to find the depth as the difference of the conservation pool elevation and the contour elevation. Then, in the ArcGIS Pro Project tab the Map and Scenes setting was adjusted to a local scene view since the curvature of the earth is insignificant for the scale of the lake. Next, in the View tab the map was converted from 2D to 3D and the contour feature was moved into the 3D Layers classification and selected. Using the Appearance tab under Feature Layer a Max Height extrusion was made using the calculated depth field. The results of this procedure are shown above in Figure 13.

Conclusion

Grapevine Lake is a manmade lake located in the southeast of the Denton Watershed subbasin. Within the subbasin there are a total of 18 subwatersheds comprising 3 watersheds, and 596 catchments corresponding to 604 stream reaches. Comparison between historic drought and reservoir storage for the lake shows that drought is good indication of conservation pool levels for the lake, which could be significant since the lake provides water for a significant portion of the Dallas/Ft. Worth Metroplex. While a digital elevation model can be useful for performing a hydrologic terrain analysis on a drainage basin, it is apparent from the flow direction, land slope, and flow accumulation over the lake that elevation data alone fails to represent the complexity of the land below the surface of open water bodies. To account for these complexities and enable more accurate hydrologic analysis, a bathymetric model for open waters is necessary. Extrusion of contour depths can be used to obtain a 3D bathymetric model, and the contour polylines can be burned into the digital elevation map to incorporate elevation data. A more accurate approach would be to represent the elevation of the lake between contours, though this would require additional tools. Polygons would need to be defined between neighboring contours with elevation data corresponding to the average of the confining contours. These polygons could then be converted into a raster format and merged with the digital elevation model so that more in depth hydrologic analysis may be performed.

References

Texas Water Development Board. (n.d.) *Water Data for Texas: Lake Grapevine*. Retrieved from https://waterdatafortexas.org/reservoirs/individual/grapevine

Texas Water Development Board. (n.d.) *Completed Surveys & Data*. Retrieved from http://www.twdb.texas.gov/surfacewater/surveys/completed/list/index.asp

United States Drought Monitor. (n.d.) *GIS Data Archive*. Retrieved from http://droughtmonitor.unl.edu/MapsAndData/GISData.aspx

US Army Corps of Engineers. (n.d.) *Grapevine Lake Information*. Retrieved from http://www.swf-wc.usace.army.mil/grapevine/Information/index.asp